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(54) HOLOGRAPHIC RECORDING METHOD

(71) We, AGFA-GEVAERT N.V., formerly Gevaert-Agfa N.V., a Belgian Company of 27, Septestraat, Mortsel, Belgium, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

In the recording of a hologram, the angular separation between the reference beam and the image beam is usually kept small in order to reduce the required resolution of the recording material. As a consequence thereof, little freedom is left as to the optical set-up of the recording and the reproduction arrangement since the source directing the reference beam onto the hologram and the area where the reconstructed hologram appears as a virtual image, are located close to each other at the side of the hologram which is remote from the eye. Moreover, when the angular separation is very small, it becomes inconvenient to view the reconstructed image at distances close to the hologram, since the reference beam, or the zero-order beam, which is relatively intense, may easily reach the eye of the viewer.

According to the present invention a holographic recording method is provided which permits a greater freedom in the location of the source producing the reference beam with respect to the object. The present invention thus provides a method of recording a hologram of an object wherein a radiation-sensitive recording material in optical contact with one face of a prism is simultaneously exposed to a reference beam which enters the prism through a second face thereof and to an image beam which enters such prism through a third face thereof and the reference beam enters the recording material at an angle such that it is substantially completely internally reflected within the recording material.

In the description hereinafter, only the case will be considered wherein the medium through which the radiation beam travels to and from the prism-recording material system is air. It is to be understood however that such medium may be any other transparent gaseous medium with a refractive index which is lower than that of the prism material or the recording layer, and which preferably does not substantially differ from 1.

The term "prism" as used herein denotes a transparent prismatic body, e.g. a body of triangular, quadrangular or rhombic section, which body is preferably a solid, such as glass, but may alternatively comprise a liquid mass enclosed within transparent walls with which the liquid is optically isotropic.

The term "optical contact" used with regard to the prism and recording material in the present specification means that between the prism and the recording layer no medium is present unless its refractive index is substantially the same as either that of the prism, or that of the layer of recording material.

The mentioned optical contact may, e.g. be established by coating a light-sensitive recording layer directly onto one face of the prism.

As an alternative, a recording material may be used which comprises a radiation-sensitive recording layer, e.g. a silver halide emulsion layer carried by a conventional support such as a glass plate or a triacetate or polyester film, and such recording material may be held in direct contact with the prism by mechanical pressure, or, there may be an intervening layer of a liquid or adhesive medium the refractive index of which is the same as that of the prism and the support. In the case where the silver halide emulsion layer is next to such an intervening medium, this medium must be of such composition that it does not alter the sensitometric or chemical properties of the recording layer.

A said intervening medium may be liquid, in which case the recording material is not permanently united with the prism. Alternatively an adhesive may be used as a said intervening medium so that the recording layer is permanently united with the prism.

Either the support or the radiation-sensitive emulsion of the recording material preferably contains radiation absorbing dyes to prevent multiple internal reflection of the radiation

within the recording material. Alternatively the recording material may include an additional layer incorporating such dyes.

The hologram may be reconstructed by directing a read-out beam onto the developed record through the prism so that the read-out beam follows a course through the prism corresponding with that which was traversed by the reference beam. In practice the reference and read-out beams are virtually identical but the read-out beam may be of higher intensity.

The hologram record which is used for the reconstruction of the hologram may be the original hologram record which was formed upon exposure and development of the recording material, or a copy of such original record.

Accordingly the present invention also includes a method of recording a hologram of an object and reconstructing the hologram to give a virtual image, wherein a latent record of the hologram is formed in a radiation-sensitive recording material by a method according to the invention and wherein after developing the said latent record and while the developed record or a copy produced therefrom is in optical contact with one face of the prism used in said recording method or another like prism, a read-out beam is directed into such prism along a path substantially corresponding with that traversed by said reference beam during the recording of the hologram.

If only the one prism is located in the beam reflected from the object during the recording of the hologram, the reconstructed hologram will be aberrated. According to a particular embodiment of the invention, such aberrations are avoided by effecting the recording of the hologram through a second prism located at a small distance (e.g. less than a millimetre) from the first one, but having an inverted position. In the reconstruction of the hologram to give a virtual image it does not make any difference whether said second prism is left in place or is removed.

The invention is described hereinafter by way of example with reference to the accompanying drawings, wherein:

Fig. 1 shows an arrangement for carrying out the method according to the present invention,

Fig. 2 shows another arrangement, wherein the aberration of the recording image is avoided.

Fig. 3 shows an arrangement comprising a quadrangular prism.

In the arrangement which is diagrammatically shown in figure 1, a hologram is recorded in a recording layer 10 which is provided on the first face 11 of a triangular prism 15, shown in outline in the figure. For clearness' sake, the relative thickness of the recording layer in respect of the prism has been increased.

The recording layer 10 actually is a silver halide emulsion layer with high resolving power and sensitized for the laser's monochromatic radiation. Furthermore, the emulsion contains a concentration of dyes which is sufficiently high to absorb a substantial amount of the light used for producing the hologram.

The prism is made of ordinary glass such as that used for conventional photographic plates, and its faces are optically flat. The photographic emulsion is coated directly onto the mentioned first face 11 of the prism. The operation of coating the emulsion on the prism may occur on a coventional coating apparatus for coating photographic emulsions on glass plates. To this end, the prism may, either alone or together with other prisms, be clamped in a frame with its face to be coated located upwardly and running strictly horizontal. The frame is supported and advanced over driven rollers and passes under a coating station where the coating composition is flowed to the upperside of the prism or the prisms.

The recording of the hologram occurs as follows. A laser, not shown in the figure, emits a coherent light beam, a part 14 of which enters the prism substantially normally through its second face 12 as the reference light beam. The beam falls onto the prism-air interface 13 at an angle which is greater than the critical angle for total reflection thereof i.e. about 42°, so that the beam is totally internally reflected and passing the prism-layer interface 11, penetrates into the recording layer 10. A part 16 of the coherent light beam which has been derived by appropriate deflection from the main beam illuminates the object 17. The image-beam, consisting of light reflected from the object 17 enters the prism through the third face 13 and interferes with the reference beam in the recording layer.

As a consequence of absorbing dyes contained in the emulsion layer 10 the interference pattern of the reflected image beam with the reference beam is confined to the bottom of the emulsion layer, i.e. the side which is in contact with the prism. The recording material is now developed in a conventional way to form a silver image with a density of about 1, and the dyes are bleached out.

The reconstruction of the virtual image from the hologram obtained occurs as follows. A read-out laser radiation beam is used which runs substantially parallel to the reference beam used for the recording, and which enters the prism through the face 12. The beam impinges on the emulsion layer 10, at substantially the same angle as occurred during the recording and a wave pattern is produced so that the eye 18 sees the virtual image of the object at the original position of the object 17. The read-out beam does not leave the emulsion layer 10 since its angle of incidence on the emulsion-air interface is greater than the critical angle thereof: instead, it is reflected as shown by the broken lines, but since

the emulsion layer has been developed to a density of about 1, it is absorbed in said emulsion layer and no multiple reflections will occur.

The absorbing dyes in the emulsion layer prevent multiple internal reflections which tend to occur when the angle of incidence is greater than the critical angle. The separation between read-out and image beams is such as to obviate any serious risk of the operator's eye receiving the read-out beam.

The prism of the arrangement just described was right-angled, and the acute angle α which is adjacent to the coated face of the prism measured about 24 degrees. It is clear that the angle α of such a prism may have other values, provided that it is less than or equal to half the complement of the critical angle. Furthermore, the prism may have an obtuse angle, rather than a right angle, and the mentioned angle α may have smaller or greater values, provided only that the angle of incidence of the reference beam on the recording material-air interface is equal to or greater than the critical angle.

In the arrangement described hereinbefore, the interference pattern recorded in the emulsion layer does not permit a true reconstruction of the original image because the image beam reflected from the object becomes aberrated while passing through the prism.

This aberration can be easily avoided by locating another similar prism at a small distance from the first one, but in an inverted position, so that the image beam enters through a face which runs parallel to the plane of the recording layer.

An optical set-up wherein the aberration of the image beam upon recording is avoided and wherein the emulsion layer is not directly coated on the prism, is shown in fig. 2.

The arrangement comprises a right angled glass prism 15 which, through an intermediate layer 19, is in optical contact with a recording layer 21 coated on a film support 20.

During the exposure the light beam which is reflected from the object 17 passes through the additional prism 22 before it enters the prism 15. The prism 22 is similar to the prism 15 and it is arranged so that its oblique face runs parallel to that of the prism 15 at a distance of three tenths of a millimeter. The refractions at the different prism-air boundaries are illustrated exaggeratedly. It is clear that in the arrangement described the light rays leaving the layer 20 to the eye run parallel to those extending between the virtual image (object) and the prism 22.

The intermediate layer 19 serves to establish optical contact between the recording layer 21 and the prism and therefore has a refractive index which equals that of the prism and the recording layer.

The chemical properties of the intermediate layer are such that neither the prism nor the film are affected, and/or the sensitometric properties of the recording layer are not altered. As liquids and other compounds suitable for the present application are well known in the photographic art, no further details are given thereabout hereinafter.

When, as shown in the figure, the film is applied with the recording layer against the prism, the bond between the recording material and the prism should be temporary so that the film may be removed from the prism in order to process the recording layer. To this end, an intermediate layer of liquid may be used and the film strip and prism may be held together by a clamp or by adhesive tapes. After the hologram has been formed, the film strip is applied again against the prism for reconstructing the virtual image, this time the strip may be permanently bonded to the prism, e.g. by means of an adhesive.

If contrary to what is shown in the figure, the film strip is applied with the support 20 against the prism, the intermediate layer may constitute a permanent bond between the film strip and the prism, and in that case the prism together with the film strip may be immersed into the liquids for processing the recording layer after the exposure.

For the reconstruction of the virtual image from the hologram, it does not matter whether the additional prism 22 is left in place or not since it is the image of the interference pattern formed in the recording layer 21 which is seen by the eye.

An interesting application of the present invention consists in mounting a small hologram on a prism base in an appropriate frame, supported for instance by a kind of helmet so that it is positioned close to the eye and may move together with the head. In this way an operator may permanently view the image of e.g. an ordinance map or of an instruction card. The surface area of such hologram need be no greater than a few times the area of the average pupil's surface. The read-out beam may be produced in a convenient way by a source mounted on the helmet and the beam of which is directed to the prism, e.g. by means of fiber optics.

An arrangement wherein a quadrangular prism is used is shown in figure 3. On the face 26 of the quadrangular prism 25 is coated a recording layer 27 and on said layer an absorbing layer 30 is applied. The recording layer 27 is a conventional silver halide emulsion layer for holographic applications which contains no particular dyes for the absorption of the interference pattern as described hereinbefore in connection with the example of figure 1. The layer 30, on the contrary, does contain absorbing dyes. Its function corresponds generally to that of conventional antihalation layers, and in this respect reference may be had in literature as to the choice of suitable dyes. A radiation absorbing layer,

when used, such as the layer 30, is to be considered as part of the recording material.

The beam 28 which is reflected from the object to be recorded enters the prism through face 29 which is strictly parallel to the face 26. Thus no aberration of the recorded pattern will occur.

The reference beam 14 enters the prism through face 31 and impinges on the face 26 at an angle which is greater than the critical angle of the recording material-air boundary. The reference beam passes through the recording layer 27 and enters the layer 30 where it is totally internally reflected. Multiple internal reflection within the recording material is prevented by virtue of the absorption of the reflected radiation by the said absorbing dyes.

The exposed material is processed and the silver image is developed to a density of about 1. The layer 30 is bleached out, or stripped off in case it has been arranged for the latter treatment, since the density of the silver image is such as to eliminate the effects of possible multiple reflections of the read-out beam at the layer-air interface.

The hologram record from which the hologram is reconstructed need not necessarily be the original hologram record but it may be a copy thereof. Thus, according to the example described in connection with figure 2, the film strip may be removed from the prism after the exposure, processed, and a copy produced therefrom may be secured, either in a temporary or in a permanent way, to the face of the prism whereon the original recording layer was located.

The feature that the hologram record, either the original hologram record or a copy thereof, may be removed from the prism may serve another useful purpose, vis. the storage of a recording material for the application of the method according to the invention in a relatively restricted space. Thus it is possible to make and store a great number of hologram records on film sheets or strips, while only a limited number of viewing apparatus including a prism and a radiation source producing the read-out beam need be kept.

WHAT WE CLAIM IS:—

1. A method of recording a hologram of an object wherein a radiation-sensitive recording material in optical contact with one face of a prism is simultaneously exposed to a reference beam which enters the prism through a second face thereof and to an image beam which enters such prism through a third face thereof and the reference beam entering the recording material at an angle such that it is substantially completely internally reflected within the recording material.

2. A Method according to claim 1 wherein the recording of the hologram occurs without aberration by locating a second prism between the object to be recorded and the first prism so that the image beam enters said second prism through a face which runs parallel to the recording material and passes from the second to the first prism through faces which run parallel to each other.

3. A Method according to either of the preceding claims, wherein the reference beam is reflected on at least one prism-air interface before falling on the recording material.

4. A Method according to any of the preceding claims, wherein the recording material is sufficiently radiation absorbent to prevent multiple internal reflection of the reference beam in such material.

5. A Method according to claim 4, wherein the recording material comprises a radiation-sensitive layer containing a radiation-absorbing dye which prevents said multiple internal reflection and which can be bleached out during developement processing of the recording material.

6. A Method according to claim 4, wherein the recording material comprises a radiation-sensitive layer and a layer comprising a radiation-absorbing dye which dye layer prevents said multiple internal reflection, such dye being removeable or bleachable after exposure thereof.

7. A method of recording a hologram of an object substantially as hereinbefore described with reference to the accompanying drawings.

8. A Method of recording a hologram of an object and reconstructing the hologram to give a virtual image, wherein a latent record of the hologram is formed in a radiation-sensitive recording material by a method according to any preceding claim, and wherein after developing the said latent record and while the developed record or a copy produced therefrom is in optical contact with one face of the prism used in said recording method or another like prism, a read-out beam is directed into such prism along a path substantially corresponding with that traversed by said reference beam during the recording of the hologram.

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1289095 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale

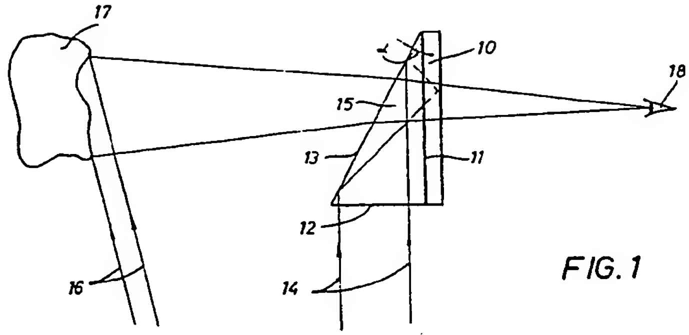

FIG. 1

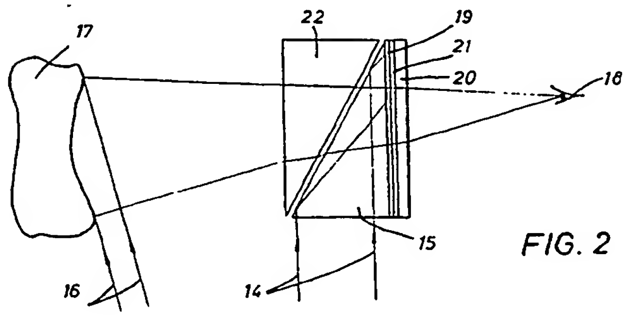

FIG. 2

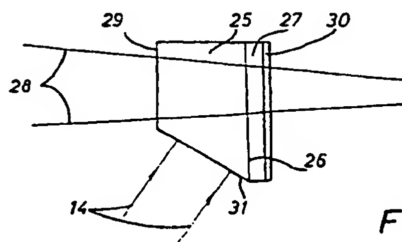

FIG. 3